Synthesis of Juvenile and Adult Salmon Studies at the Hiram M. Chittenden Locks

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In 1995 the Locks became an ongoing experiment in *adaptive management* aimed at improving juvenile salmon survival through the project and ultimately resulting in the current integrated smolt passage system (a combination of surface bypass outlet and behavioral guidance). Adaptive management projects or actions must have a series of elements to ensure some measure of success – hypothesis testing, performance measures, experimentation, monitoring, evaluation, and feedback in modifying the project or action. Actions at the Locks began by identifying initial questions or hypotheses to test including 1) are smolts entrained and injured through the large lock filling culverts; 2) will low-flow smolt passage flume(s) safely pass smolts; and 3) are there behavioral techniques available that can guide smolts away from culvert intakes. A series of experiments (with monitoring and evaluation) were conducted from 1995 to 1998 to test these hypotheses including 1) entrainment with and without behavioral guidance techniques including strobe lights, low-frequency sound, and different filling techniques of the large lock; and 2) smolt counts over a single smolt passage flume. Evaluation of these experiments became the basis to revise the initial hypotheses and conceptualize a new restoration project (and experiments) that was implemented beginning in 2000. New hypotheses developed included 1) smolt passage flumes (SPF) will pass 65% of all smolts migrating through the project; 2) strobe lights will reduce smolt entrainment by 50%; 3) slowing the lock filling rate (or increasing the lock fill time) will reduce smolt entrainment by 50%; and 4) barnacle removal (BR) will reduce injury rates by 50%. Monitoring results from the last three years show 1) 95% or more of all smolts pass over the flumes with 3 or more flumes in operation; 2) smolt entrainment is reduced by 75% with strobe lights; 3) slower fill time (SFT) shows a trend of decreasing entrainment with decreasing fill rate – 1) SFT1 (5 min) reduces entrainment by 30% over baseline (4 min); 2) SFT2 (10 minutes) reduces entrainment by 40% over SFT1; and 3) SFT3 (14 minutes) reduces entrainment by 60% over SFT1; and 4) barnacle removal reduces injury rate by 75%.

Comparing results between years shows overall project improvement in juvenile salmon fish guidance over time. Relative fish guidance efficiency (RFGE) is a composite performance measure tracking the percentage of fish passed over the smolt passage flumes relative to large lock culvert entrainment. RFGE is related to which restoration elements are being tested within a year and which volume of water is passed through the SPF: for comparison purposes between prototype and current four flumes, I use two levels of SPF volume - less than 100 cfs and greater than 100 cfs. By year RFGE has changed from 1) 1996 33% (SPF <100 cfs); 2) 1998 60% (SPF <100 cfs, SFT1); 3) 2000 97% (SPF >100 cfs; SFT2) and 54% (SPF<100 cfs; SFT2); 4) 2001 95% (SPF>100 cfs; SFT2) and 37% (SPF<100 cfs; SFT2); and 5) 2002 96% (SPF>100 cfs; SFT2) and 59% (SPF<100 cfs; SFT2) and 99% during strobe light testing: Note RFGE is calculated slightly differently for 2002 but is reported here for year to year comparison. Mean entrainment (fish/fill) into the lock filling culverts is one component of RFGE. By year ME has declined from 1) 1996 161 fish/fill; 2) 1998 47 fish/fill; 3) 2000-2001 27-29 fish/fill; 4) 2002 15 fish/fill and 3 fish/fill with strobe lights. Relative injury rate (RIR), another composite measure, can be calculated by multiplying the RFGE against an observed injury rate. Baseline injury rate with heavy descaling (scale loss of 10% or more on one side of the body) was 13% in 1998 prior to barnacle removal (B) and 3% in 2000 after barnacle removal (BR). By year RIR has changed from 1) 8.7% 1996 (B); 2) 5.2% 1998 (B); 3) 0.1% 2000 (BR; SPF>100 cfs) and 1.6% (BR; SPF<100 cfs); 4) 0.2% 2001 (BR; SPF>100 cfs) and 1.1% (BR; SPF<100 cfs); and 5) 0.1% 2002 (BR; SPF>100 cfs) and 1.23% (BR; SPF<100 cfs). We can use these values to predict our expected future performance in 2003 at higher flows (strobe light testing has not occurred at lower flows) with the addition of strobe lights – 99% RFGE and 0.1%< RI (SPF>100 cfs).

Based on monitoring to date, new hypotheses or questions include 1) what is the minimum flow volume that will consistently pass 95-99% or more of all smolts (with and without strobe lights); 2) do smolts migrate safely through other routes (volitional migration through lock chamber) under low flow conditions; and 3) what other factor(s) affect Lake Washington smolt to adult survival after passage through the Locks. To address the first question, a second year of testing of the relative fish guidance efficiency should be conducted (expected 2004 with funding). To address the second question, National Marine Fisheries Service (NMFS) is developing an experimental an experimental miniaturized ultrasonic (acoustic) tag and receiver node (multiple hydrophone) system. In 2003, NMFS will be conducting a pilot test of the technology with the objective of tagging 60 juvenile Chinook salmon (minimum size 90-100 mm), monitoring movement through the Ship Canal from Montlake through the Locks and into Shilshole Bay. If the technology proves effective, additional study would occur in 2004 with a full-scale release of up to 300-tagged fish. To address the third question, a coded wire tag (CWT) analysis of chinook salmon smolt to adult survival, growth and age of maturation is being conducted by Greg Ruggerone, Natural Resource Consultants. Results from initial analysis – survival, growth and maturation of Puget Sound chinook salmon in relation to pink salmon abundance are included as attachment 1. Results for Lake Washington are consistent with the overall results.

Monitoring of adult chinook salmon began in 1998 and continued through 2000. Initial monitoring identified some unexpected results including 1) most adults migrate through the fish ladder at increasing tidal height, through variable salinity (0-10 ppt) and under extreme temperatures (up to 22 C); 2) all tagged adults immediately moved from the fish ladder to an area just upstream of the saltwater drain intake and large lock; and 3) adults remained in this area from 1 to up to 47 days. This resulted in development of hypotheses regarding adult chinook salmon behavior, the Ship Canal environment, and Locks operations including 1) high water temperatures (and/or low dissolved oxygen) further upstream of the Locks are a barrier that adults will not swim through; 2) the area immediately upstream (within 1000 ft) of the Locks is a necessary cool water refuge where adults can safely hold until temperatures drop; and 3) what series of lock operations can improve the quality (dissolved oxygen, temperature, salinity) of the cool water refuge (and how do chinook respond to operational changes). The first question is outside our current area of monitoring, but data from ambient monitoring shows adverse conditions of high water temperatures upstream of the Locks (20 C as indicator) have been increasing in duration from 30 days/year in the 1970's to 90 days/year in the 1990's while dissolved oxygen levels may fall below 5 mg/l in most years. A series of lock operation settings were developed and monitored to provide data to explore the second and third hypotheses. In 2000, adult chinook salmon behavior and water quality conditions were monitored during the operational testing. Initial data analyses showed aggregate fish position – 1) 80% of all hours were spent in the vicinity of the drain and lock entrance; 2) mean fish depth was 7.0-7.4 m and varied little from beginning of monitoring to end of monitoring. In relation to water quality conditions the mean depth of fish was found at 1) salinity values of 0.5-1.0 ppt; 2) temperature of 20.5-21.5 C; and 3) dissolved oxygen levels of 7.5 mg/l at the beginning of the study and 6.7 mg/l at the end of the study. This level of analysis was considered insufficient to address the question of fish use in relation to environmental parameters. Unlike juvenile salmon studies to date, changes to Lock operations that might affect adult chinook could be tested using ecological modeling that should allow evaluation of adaptive actions without changes in locks structure or operation.

To evaluate the monitoring data a coupled ecological model linking a hydrodynamic model (computational fluid dynamics (CFD) model) of the Ship Canal and a fish behavior (numerical fish surrogate) model is being developed. This model can be used to further explore the monitoring data (fish behavior in response to environmental change), evaluate the hypotheses, and possibly to test and evaluate new scenarios of Lock operations or structural changes. The coupled ecological model has been demonstrated in application to juvenile salmon migration through the reservoir and dam at Lower Granite Dam on the Snake River. The model was developed to understand how juvenile salmon (steelhead) hydraulically navigate complex flow fields. Work on the Locks model in 2003 (if funded) would include a similar analysis to the Lower Granite dam model that relates the behavior of adult salmon in the Chittenden Locks to patterns in flow, temperature, and salinity (DO might be added to the model). This analysis is conducted by interpolating information from the CFD output to specific fish positions obtained from the fish tracking data sets. This integrated data set can then be used to statistically determine the variables and their relative weights that determine the swim path selection behavior of adult salmon. Such information is critical to changing the operation of the Locks and upstream water quality in the system to help restore salmon. Ultimately the hope is that the model can be used to quantitatively evaluate each possible operational scenario or design alternative considered for the Locks by using virtual fish programmed to respond according to rules uncovered during the system analysis of the integrated data sets. This latter step has only been achieved at a reasonable level in one other project (Lower Granite) so there is some uncertainty as to the success for the Chittenden Locks. However, if successful, this would take much of the uncertainty out of salmon restoration activities that involve major hydraulic redesign or changes in water management practices. Data will be presented that illustrate adult migratory behavior at the project with some initial plots of the coupled ecological model.

Attachment 1

Survival, growth, and age at maturation of Puget Sound chinook salmon released during odd- versus even-numbered years: evidence for interspecific competition with pink salmon during early marine life

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Potential competition between pink and chinook salmon originating from Puget Sound, Washington, was tested using recovery rates of coded-wire-tagged subyearling hatchery chinook salmon (*Oncorhynchus tshawytscha*). Pink salmon (*O. gorbuscha*) in Puget Sound enter marine waters in even-numbered years and invariably return as adults during the following odd-numbered year; almost no juvenile pink salmon migrate to marine waters during odd-numbered years. During release years 1984-1997, juvenile chinook salmon released during even-numbered years, corresponding to years of abundant juvenile pink salmon, experienced 62% lower survival compared with those released during odd-numbered years, a trend that was consistent among all 10 chinook salmon stocks. Age-specific survival rates were significantly lower among all age groups, indicating the differential mortality occurred during the first year at sea. Chinook salmon released during even-numbered years experienced reduced growth and delayed maturation, indicating growth rate was a key factor affecting survival. A similar pattern was seen in lower British Columbia mainland streams, where even-year juvenile pink salmon are abundant, but not along the Washington coast and lower Vancouver Island, where few pink salmon originate. During 1972-1983, pink salmon abundance was low and average survival of chinook salmon was relatively high, but no significant odd/even year pattern was detected. From 1972-1983 to 1984-1997, average chinook salmon survival in Puget Sound declined 50%, adult pink salmon abundance nearly doubled, and herring, a key prey species of juvenile chinook salmon, declined significantly. The observed odd/even year effect accounted for 77% of the decline between the two periods. These data suggest that pink salmon and forage fish availability have had a major effect on growth, survival and age composition of Puget Sound chinook salmon, which are presently protected under the U.S. Endangered Species Act.